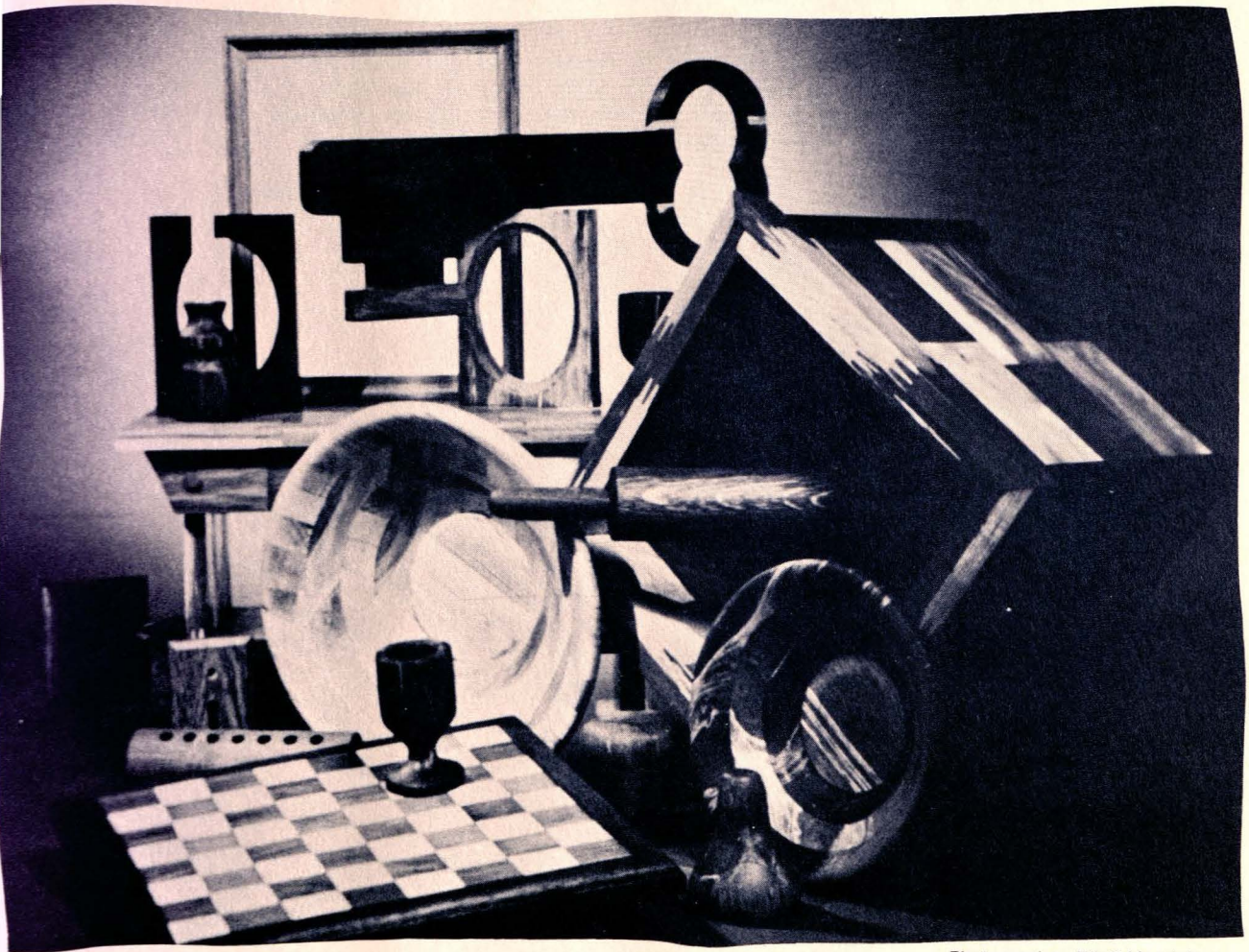
USDA FOREST SERVICE
GENERAL TECHNICAL REPORT NC-10
1974

how craftsmen & home hobbyists can make and use wood plastic composite materials



Photographer: Eliott Mendelson

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

howard n. rosen

HOWARD N. ROSEN is a Research Chemical Engineer for the Station at its Forestry Sciences Laboratory in Carbondale, Illinois. The Laboratory is maintained in cooperation with Southern Illinois University.

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COVER PHOTO by Eliott Mendelson of *The Daily Egyptian* at Southern Illinois University, Carbondale, Illinois.

North Central Forest Experiment Station
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(Maintained in cooperation with the University of Minnesota)

Rosen, Howard N.
1974. How craftsmen and home hobbyists can make and use wood-plastic composite materials. North Cent. For. Exp. Stn., St. Paul, Minn. 9 p., illus. (USDA For. Serv. Gen. Tech. Rep. NC-10)

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OXFORD: 842:843:U689. KEY WORDS: methyl methacrylate monomer, gluing, curing, machining.

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HOW CRAFTSMEN AND HOME HOBBYISTS CAN MAKE AND USE WOOD-PLASTIC COMPOSITE MATERIALS

Howard N. Rosen

INTRODUCTION

How would you like to make soft maple or aspen harder, more colorful, more dimensionally stable, and easier to finish than the highest quality hardwoods? These benefits and many more are possible using WPC, which is an acronym recognized by professional woodworkers for wood-plastic composite materials. Its use also affords more versatility in the design of wood items ranging from tiepins to tabletops, produced in the home, school, or small shop.

WPC is formed when wood is filled with a plastic *monomer* and then heated in an oven. WPC combines the toughness, abrasiveness, and hardness of plastic with the intricate grain structure and strength of wood to make a most appealing amalgam. These plastic characteristics make WPC more durable and resistent to warping and swelling during changes in humidity than untreated wood. Moreover, the grain of the wood is accentuated in a satin-smooth surface of unfinished WPC. Addition of dyes can ensure even color throughout a WPC Product.

WPC is not without some disadvantages compared to wood. WPC is more costly than wood ($1 to $2/board foot higher) and it is more difficult to glue and to work. Futhermore, distortion can occur during polymerization; thus, greater care must be given to specifying dimensions when WPC is used.

HOW WPC IS FORMED

Chemically, plastics are made by linking small molecules called monomers together to form long chains of molecules called *polymers*. The process, called *polymerization*, has been used to make WPC by two methods: (1) bombardment with gamma radiation or (2) heating of catalyzed monomer. Many different monomers that exist as a liquid at room temperature can be polymerized to form WPC.

Monomers, such as methyl methacrylate, vinyl acetate, and styrene, can be used to form WPC. The most popular monomer used in WPC work is methyl methacrylate, known commercially in the polymerized form as Plexiglas or Lucite.[1] This monomer is recommended for small shop work with WPC material for the following reasons:

1. The low heat of polymerization reduces the chance of charring the wood.

2. The monomer is readily obtained through a number of companies.

3. The WPC material made with this monomer machines very well.

4. The monomer has a low toxicity.

Styrene monmmer is a second choice to make WPC. It is not as desirable as methyl methacrylate because of odors that remain in the treated wood. A list of properties is given for methyl methacrylate and styrene below:

	Methyl methacrylate	*Styrene*
Boiling point (°F)	214	293
Density at 25° C (gm/cc)	0.94	0.90
Flash point-Tag open cup (°F)	55	94
Heat of polymerization (kCal/mole)	13.3	17.8
Viscosity at 25° C (cp)	.6	.7
Cost (dol/lb)[2]	.27	.16

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[1] *Use of trade names does not constitute endorsement of the products by the USDA Forest Service.*

[2] *Prices are based on 55-gal. drum and will increase for smaller quantities. Five-gal. quantities are available for $16 or about $0.40/lb.*

Pure monomers can spontaneously polymerize during storage at room temperature. Spontaneous polymerization can be delayed by the addition of a chemical called an *inhibitor*. Typical inhibitors are hydroquinone (HQ), butyrated hydroxyl toluene (BHT), and monomethyl ether of hydroquinone (MEHQ). Retailers of monomers will give the purchaser a choice of inhibitor and inhibitor concentration. The decision concerning inhibitor amounts depends on how soon the monomer will be used. If the monomer will not be used over the course of a year, a higher amount of inhibitor should be used. For example, at 75°F, 10 parts per million (p/m) addition of MEHQ inhibitor will increase the life of methyl methacrylate monomer from 2 weeks to 2 years; 50 p/m of MEHQ will increase the life to 20 years. If possible, the higher concentrations should be avoided because the inhibitor decreases the effectiveness of the catalyst.

The basic process used to make WPC in the workshop is the catalyst-heat method. The monomer solution is forced into the voids of the wood structure and then *cured* (monomer becomes polymer) with heat. Because the formation of the plastic polymer causes considerable heat to be released (called the *heat of polymerization*), the heating of the monomer-soaked wood must be at a moderate temperature so the wood is not charred.

EQUIPMENT NEEDED

Most of the equipment necessary to form the WPC can be found around the home or workshop. The following general equipment is needed to make WPC. An example is given for appropriate items that can be used:

Weighing device--kitchen scale.
Impregnation tank--3-in. diameter galvanized pipe with end caps.
Surge tank--1-gal solvent bottle with two-hole rubber stopper.
Vacuum supply--water aspirator (filter pump).
Monomer supply tank--1-gal bottle.
Tubing--thick-walled vacuum rubber tubing.
Oven--roof de-icing heating tape and steel pipe.
Aluminum foil
Masking tape
Hose clamp

The supplies can be obtained at a hardware store except for the water aspirator, which can be obtained from a chemical supply house for about $3. A pressure and vacuum gauge used to monitor pressures during treatment is optional.

The impregnation tank can be any size or design providing it is capable of holding a vacuum and withstanding any pressure that might be applied to it. A galvanized steel nipple capped on both ends serves this purpose. The nipple is tapped so that a valve and/or pressure gauge can be attached.

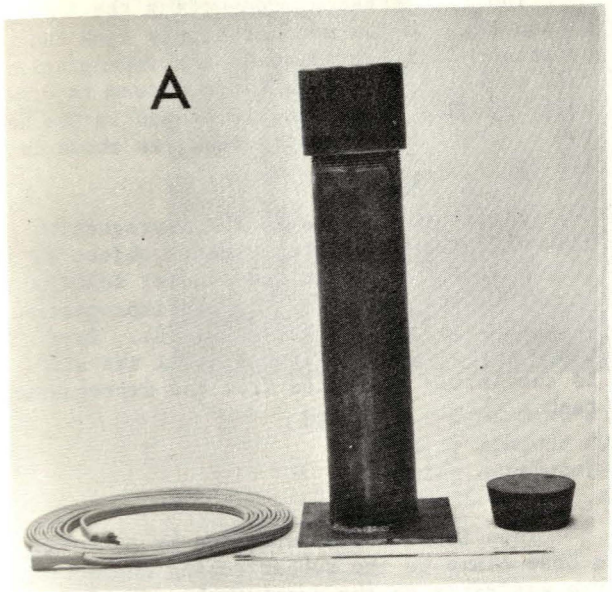
The surge tank should be capable of sustaining a vacuum without imploding. The tank can be wrapped with fine mesh window screen for added safety. A surge tank of at least five times the volume of the monomer solution is necessary to maintain a low vacuum once the monomer is introduced. Monomer solutions contain dissolved air, which is released when the monomer is introduced under vacuum.

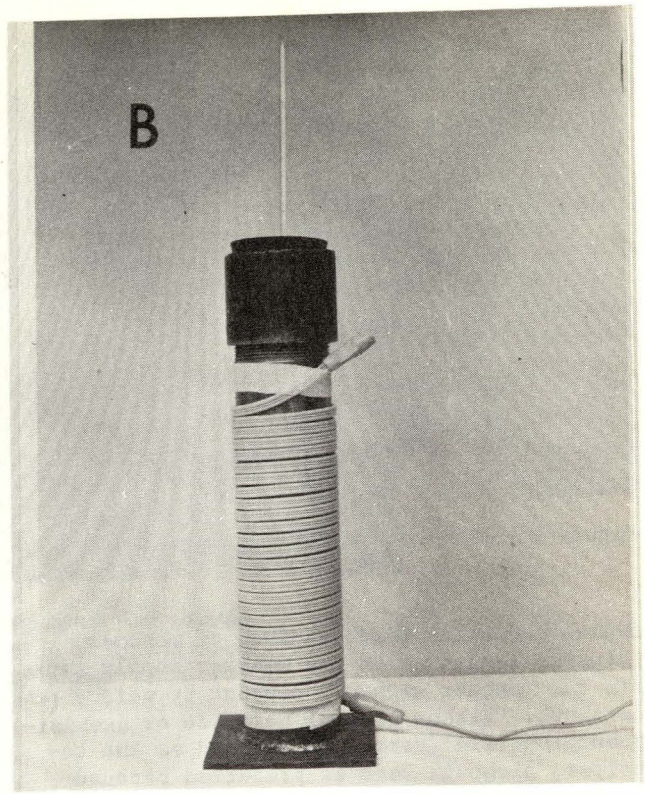
Two safe and easily constructed ovens are shown in figure 1. The first oven consists of a 25-ft length of 125 watt roof de-icing heating tape wrapped around a 3 1/2 in. galvanized pipe. The impregnated wood is placed in the pipe and loosely capped with a rubber stopper. A thermometer is inserted into the oven through a hole in the rubber stopper (figs. 1A and 1B). The second oven consists of a pickle jar placed in a coffee can filled with cooking oil. A small immersion heater is placed in the coffee can and a light dimmer switch is used to adjust current until 140 to 155° F is maintained. The pickle jar is loosely covered with a rubber stopper. Temperatures are measured using a thermometer extended through a hole in the rubber stopper into the jar. Treated wood is placed in the pickle jar for curing (figs. 1C and 1D). Exact temperature control is not required, but the closer the temperature is to 140 to 155° F, the shorter the curing time. Temperatures in excess of 155° F will evaporate the monomer before it polymerizes.

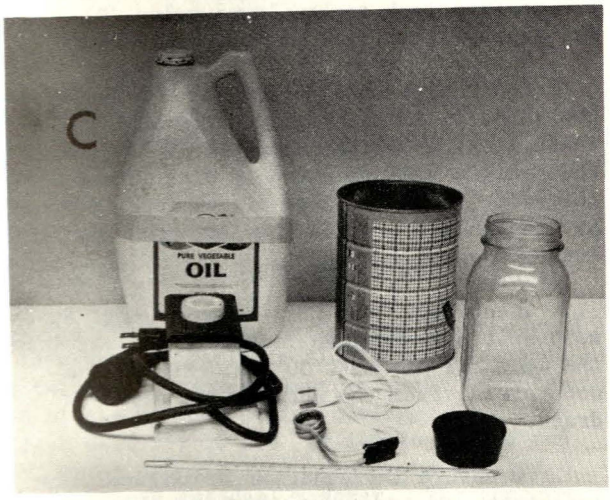
PREPARING THE WOOD

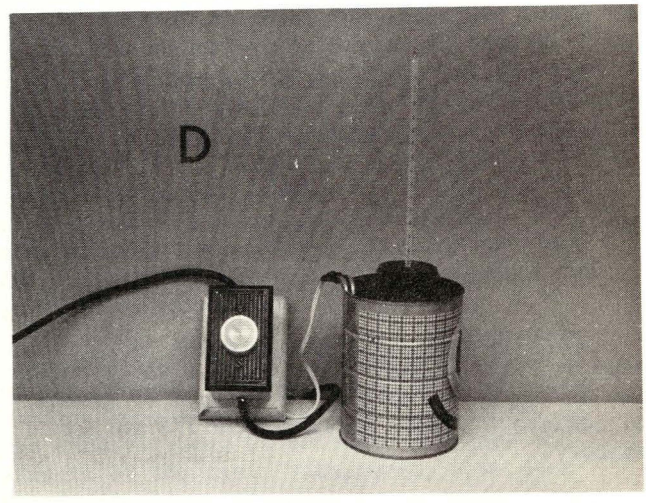
Wood used in making WPC should be dried to 6 to 12 percent moisture content. Green wood cannot be used because the wood voids are filled with water; thus, the monomer cannot enter the wood. For the best results in making WPC,

Figure 1.--*(A) Parts for a pipe-oven; (B) assembled pipe-oven; (C) parts for an oil bath oven; (D) assembled oil bath oven.*









easily penetrated woods such as soft maple, birch, aspen, cottonwood, and basswood, should be used because they have an open and interconnecting structure. Difficult-to-penetrate woods, such as red oak, white oak, and black walnut, can be used but the treatment is more difficult and the plastic is not as uniformly distributed throughout the wood.

The wood can be rough-shaped before treatment. In most cases, reshaping is necessary after forming the WPC because of dimensional changes during the curing step.

PREPARING MONOMER SOLUTIONS

Weigh the components of the monomer solution on a kitchen scale (or gram balance) as shown in figure 2. Enough catalyzed monomer solution should be made to cover the wood pieces in the impregnation tank by several

Figure 2.--*Weighing portions for monomer mixture.*

inches and still leave an inch of monomer solution remaining in the monomer supply tank. Mix the monomer with 0.2 percent by weight catalyst. Either benzoyl peroxide or azobisisobutyrontrile (Vazo) can be used as the catalyst, although Vazo is preferred because it prolongs monomer storage life and gives greater color stability. The catalysts sell for about $2/pound. If color is desired, add 1 percent by weight of dye to the solution. An optional crosslinking agent, ethylene glycol dimethacrylate (EGD), which costs about $2 per pound, will make the wood easier to sand and machine.

IMPREGNATING THE WOOD

Arrange the equipment as shown in figure 3. Attach the aspirator to a water outlet having a pressure of 20 lb/in.^{2} or greater to achieve a vacuum of less than 1/3 in. of mercury.

Plug the surge tank with a two-hole stopper. Insert a tube of some rigid material, such as plastic, into the left hole. This tube must be long enough to extend to the bottom of the surge tank. Insert another tube of rigid material into the right hole; this tube should not protrude more than 1 in. into the surge tank. This ensures that any water backup from the aspirator fills the surge tank, not the impregnation tank.

Connect thick-walled tubing capable of supporting a vacuum from the aspirator to the rigid tube in the left hole of the stopper and connect the rubber tubing from the impregnation tank to the rigid tube in the right hole. This tubing system must be free of leaks; otherwise a vacuum cannot be maintained.

The rubber tubing connecting the impregnation tank to the monomer supply tank can be attached to the valve on the impregnation tank either before or after a vacuum is drawn; however, this tubing should extend to the bottom of the monomer supply tank, as shown in figure 3.

Place wood pieces in the impregnation tank weighted with a heavy metal object so they will not float in the monomer solution. Open the upper valve (A) on the impregnation tank and close the lower valve (B). Turn the water on and let it run until the air is completely evacuated from the impregnation tank.

Then isolate the aspirator by attaching a hose clamp to the rubber tubing connecting the aspirator to the surge tank. If you have not already done so, connect the tubing from the monomer tank to the lower valve (B) on the impregnation tank and open valve B.

Add enough monomer so that the level of the solution in the impregantion tank is at least 2 in. above the wood pieces; otherwise, the plastic will be unevenly distributed in the wood. Soak the wood pieces under vacuum at least 5 min., while the entrapped air flows into the surge tank.

Then remove the hose clamp so that atmospheric pressure can force the monomer into the wood for at least 30 min. Remove the wood pieces from the monomer and let them drain.

To ensure impregnation in difficult-to-impregnate woods, such as red and white oak, isolate the impregnation tank from the surge tank and the monomer supply tank after the ordinary 30-min. soaking period. Using a compressor or pump, pressurize the impregnation tank to 50 lb/in.^{2} and let the wood pieces soak an additional 2 hrs.

The unused catalyzed monomer solution should be placed in a refrigerator and stored at about 35° F. Once the catalyst has been added to the monomer, the life of the monomer is considerably shortened. At room temperature, polymerization can occur in a

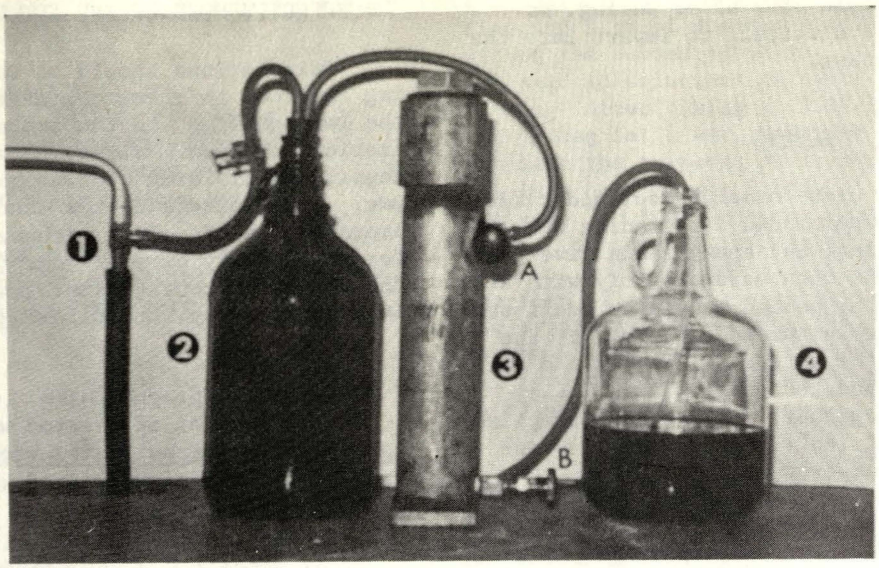


Figure 3.--*Equipment arrangement for impregnation of monomer solution into the wood: (1) water aspirator, (2) surge tank, (3) impregnation tank, and (4) monomer supply tank.*

few hours. After polymerization has occurred in the storage container, the contents cannot be removed without destroying the container.

CURING OF THE IMPREGNATED WOOD

The first step in curing the treated wood is to wrap it tightly in aluminum foil. Seal the folds with masking tape to avoid evaporation of the monomer during curing. Cure the treated wood for 10 hrs at 140 to 155° F and then unwrap and air it in a well-ventilated area to remove residual monomer. The concentrated monomer vapors can explode or catch fire so ovens with open flame or open heating elements, such as kitchen ovens, should not be used.

ADDING DYE TO MONOMER SOLUTIONS

The addition of dyes to the monomer solution gives the craftsman more versatility for creative projects. The dyes must be soluble in the monomer; thus, oil soluble dyes and not pigments are used. A colorant that is merely suspended in the monomer, such as a pigment, will separate from the monomer during impregnation of the wood and will be filtered out by the wood structure. The dye concentration in the monomer for making WPC must be greater than normally used to color plastics because the wood will require more dye for coloration. Approximately 1 percent dye gives pleasing results.

Dyes tend to inhibit the polymerization of the monomer. This inhibitation varies according to the dye used. In some cases, extra catalyst must be added to overcome the effects of the dye. Futhermore, some dyes are difficult to dissolve in monomers. The dye will more readily dissolve if it is premixed in a few drops of solvent such as acetone, methanol, or isopropyl alcohol (rubbing alcohol).

The final color of the WPC is difficult to determine without actually making the WPC material. If color is important, a test piece can be processed to determine the effects of the dye. The same dye can give varying results depending on wood type, dye concentration, monomer, catalyst, and finish. Most green

and black dyes turn blue after curing, so these colors are difficult to impart into the WPC by this process.

GLUING

Polyvinyl, urea-formaldehyde, and casein glues are not recommended for bonding WPC pieces. Resorcinol and epoxy resin give good bonding strengths when used properly with WPC. The surfaces to be bonded should be scuff sanded, the glue double spread (one-half of the adhesive should be spread on each of the mating surfaces), and the pieces assembled by clamping them together. Curing is accomplished in an oven at 140° F for 3 hrs or overnight at room temperature.

Conventional wood glues can be used to bond sections of wood before making WPC. The processing of WPC in most cases does not affect previously bonded surfaces. Glue lines will not diminish the effectiveness of the penetration but will become more noticeable in the final product because the monomer solution cannot penetrate hardened glue.

MACHINING

The WPC material can be machined on a lathe, bench saw, jointer, and drill press much the same as untreated wood. WPC material is harder and more dense than untreated wood so tool life is reduced. Carbide-tipped tools will last longer and make machining easier. The addition of a crosslinking chemical in the monomer mixture proves its usefulness in the machining and sanding of the WPC material. Without the crosslinker, the plastic in the WPC can soften and clog sawteeth, drill bits, and sandpaper. The crosslinking chemical raises the softening temperature of the plastic; thus, the material machines better. WPC will split when nailed. The material is fastened much like plastic material by being drilled and threaded for bolts or screws.

FINISHING

WPC pieces can be buffed to a high luster finish unattainable with untreated wood. Linseed or vegetable oil or wax can be worked into the surface of the piece to darken colors. If the object is to be used to serve or store food, a vegetable oil is recommended. Varnishes can be applied to further enhance the surface quality.

EFFECTIVENESS OF THE WPC TREATMENT

Calculations should be made before finishing the wood to check the effectiveness of the impregnation and the amount of polymerization achieved. First, determine your wood density by dividing wood weight by wood volume. Next, determine the *maximum* possible impregnation of methyl methacrylate or styrene for the density of your wood (fig. 4). Finally, the *actual* percentage impregnation of monomer is determined by the following relationship:

$$\text{Percent impregnation} = \frac{(\text{weight of treated wood} - \text{weight of untreated wood}) \times 100}{\text{weight of untreated wood}}$$

For easily impregnated woods, such as soft maple, the ratio of the *actual* percentage to that of *maximum* possible percentage should be greater than 0.7. More-difficult-to-penetrate woods will yield lower ratios: e.g., a value of 0.3 is reasonable for red oak. Low values of impregnation can be caused by leaks in the treating system, failure to completely submerge the wood in the monomer solution, and the use of too small a surge tank.

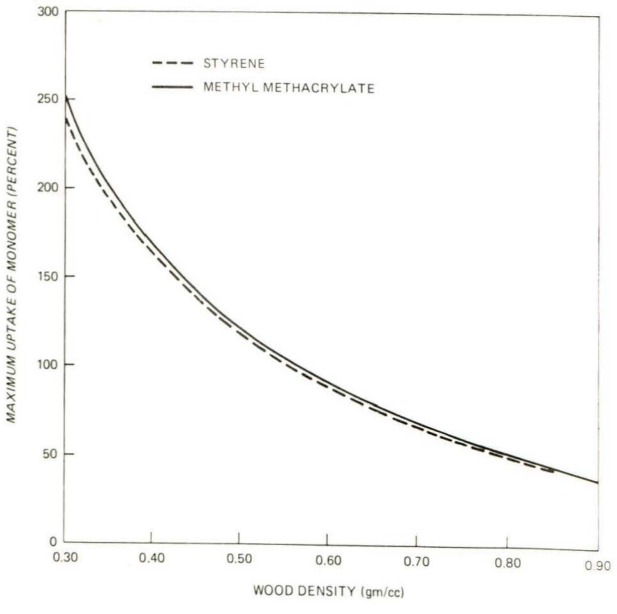


Figure 4.--*Percent of maximum uptake of monomer for various wood densities.*

The calculation to determine the amount of polymerization is:

$$\text{Percent polymerization} = \frac{(\text{weight of WPC after curing} - \text{weight of untreated wood}) \times 100}{(\text{weight of treated wood} - \text{weight of untreated wood})}$$

If the percentage polymerization is below 75 percent, there is a possibility of insufficient catalyst or too short a curing time.

SAFETY

Extreme care must be taken to ensure that vapors are not exposed to an open flame, heating element, or spark. The flash point (which indicates the flammability of substances) for methyl methacrylate (see p. 1) shows it is capable of burning and exploding at room temperature in high concentrations. The monomer, crosslinking agent, and catalyst should be stored in a cool, dark place and refrigerated if possible.

Work should be done in well-ventilated areas. Because monomers are heavier than air and collect in a layer near the floor, exhaust fans should be operating near the floor. Monomer vapors have characteristic odors and eye or throat irritation can be interpreted as a warning that the concentration in the area is too high. Safety precautions obtained from the company from which the monomers are purchased should be carefully followed.

The production of surfaces that come in contact with foodstuffs should be compatible with health regulations. Only dyes resistant to foodstuffs should be used in these cases. Vegetable oil is an accepable oil to enhance the color tone on surfaces that come in contact with food.

EXAMPLE PROJECTS

Salt and Pepper Shaker

An apple salt shaker and pear pepper shaker can be made from 1-inch-thick soft maple (fig. 5). Glue wood sections with urea-formaldehyde resin to make a piece 3 in. square by 1 ft in length. Shape the outline of the pear and apple on a lathe. Mix two monomer solutions using the following ingredients: 500 gm of methyl methacrylate monomer and 1 gm of benzoyl peroxide. Add 5 gm of a foodstuff-resistant dye to the first solution and 5 gm of another foodstuff-resistant dye to the second solution. Treat the apple and pear in solutions of their appropriate colors. After curing at 155° F overnight and air drying for 1 day, turn the final dimensions and sand the surfaces on a lathe. Drill a 3/4-inch hole in the bottom of the pear and apple to 3/8 inch from the top to form the cavity for the salt and pepper. Then drill 1/16-in. holes in the tip of the shakers in the form of an S for salt and P for pepper. Use a bottle cork to plug the holes in the bottom of the shakers. Finally, rub linseed oil into the exterior surface of the pieces to bring out the colors.

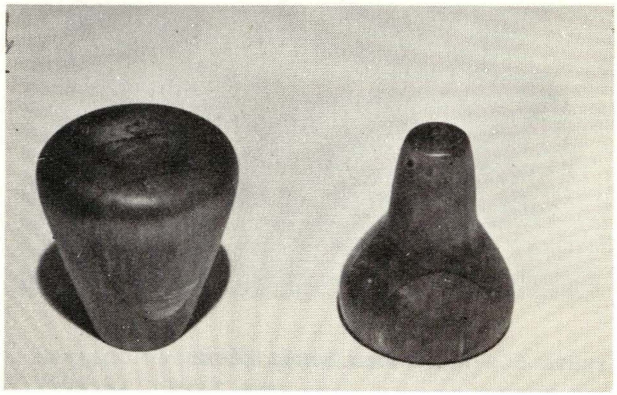


Figure 5.--*Apple salt shaker and pear pepper shaker.*

Candy Dish

A two-toned candy dish, about 5 1/2 in. in diameter and 6 in. high can be made from sticks of soft maple. Rough cut 16 sticks, 3 by 6 by 3/4 in. Mix two monomer solutions using the following ingredients: 5 lb of methyl methacrylate monomer, 1/6 oz of Vazo, and 3 oz of EGD crosslinker. Add 1 oz of dye to the first solution and 1 oz of another dye to the second. Treat half the sticks with the first monomer solution and half the sticks with the other monomer solution. After curing, use resorcinol to glue pairs of the same color sticks lengthwise to make eight 6-in. square plates. Clamp for 15 hr so the glue can set. Rough cut the 6-in. square section into disks ranging from 4 to 6 in. in diameter depending on the contour of the dish. Using resorcinal glue the disks in an alternating color pattern and again clamp for 15 hr to set the glue; seven pieces for the dish and two pieces for the top (the small

piece on top can be made using the excess from rough cutting the disks). Shape the two sections on a lathe into the dish and top. Buff and finish using a vegetable oil to produce a beautiful two-toned candy dish (fig. 6).

Figure 6.--*Two-toned candy dish.*

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Siau, J. F., and J. A. Meyer. 1966. Comparison of the properties of heat and radiation cured wood-polymer combinations. For. Prod. J. 16(8): 47-56.

LIST OF SUPPLIERS

Catalyst

E. I. DuPont de Nemours & Co. (Vazo)
Industrial Chemicals Dept.
Wilmington, DE 19898

Lucidol Division (Benzoyl peroxide)
Pennwalt Corp.
1740 Military Rd.
Buffalo, NY 14240

Crosslinker

Sartomer Co. (EGD)
Bolmar and Nields St.
Westchester, PA 19380

Dye[3]

Allied Chemical Corp. (Salvinac Red 3BS; Iosol Orange)
P. O. Box 6
Solvay, NY 13209

American Cyanamid (Calco Oil Red ZMQ)
Pigments Division
Boundbrook, NJ 08805

American Analine Prod., Inc. (Amaplast Red OB)
25 McLean Blvd.
Paterson, NJ 07509

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[3]*Any oil soluble dyes can be used; shown in parenthesis are some of the dyes used at our Laboratory in Carbondale.*

CIBA-Geigy Corp. (Irgacet Red 2BL; Irgacet Brown 2GL)
Pigments Dept.
Ardsley, NY 10502

E. I. DuPont Nemours & Co. (Oil Blue A; Latyl Orange NST)
Organic Chemicals Dept.
Dyes and Chemicals Division
Wilmington, DE 19898

Pylam Products Co.
95-10 218th St.
Queens Village, NY 11429

Sandoz Colors and Chemicals (Acetosol Blue GLS; Acetol Yellow RLS)
Route No. 10
East Hanover, NJ 07936

Glue

Ashland Chemical Co.
P. O. Box 2219
Columbus, OH 43016

Bordon Chemical
50 W. Broad St.
Columbus, OH 43215

Pacific Resins and Chemicals, Inc.
3434 13th Ave. SW
Seattle, WA 98134

Monomers

Methyl methacrylate

E. I. DuPont de Nemours & Co.
Plastics Dept.
Wilmington, DE 19898

Rohm and Haas
Industrial Chemicals Dept.
Independence Mall W.
Philadelphia, PA 19105

Styrene

Monsanto Polymers & Petrochemicals Co.
800 N. Lindbergh Blvd.
St. Louis, MO 63166

Water aspirator

A. H. Thomas Co.
P. O. Box 779
Philadelphia, PA 19105

Sargent-Welch Scientific Co.
7300 N. Linder Ave.
Skokie, IL 60076

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Sing along with Woodsy and help stop pollution.